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Visualization and quantification of helical and vortical flow in ascending aortic aneurysms

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Introduction

Complex blood flow patterns in the ascending aorta have been associated with the pathophysiology of various cardiovascular diseases, including ascending aortic aneurysms (AscAA). Helical and turbulent flow in patients with aneurysms present an increased tangential force that could lead to further aortic dilation, dissection, or rupture. Characterization and quantification of these flow patterns could help predict disease progression.

Purpose

To compare hemodynamic parameters between normal volunteers and patients with AscAA with a new 3D radially undersampled phase contrast technique (PCVIPR).

Materials and methods

PCVIPR data were acquired on 1.5 T and 3 T clinical systems (GE Healthcare, Waukesha, WI) after obtaining informed consent according to our IRB protocol in 10 volunteers and 11 patients with AscAA. Typical scan parameters were: imaging volume = 320 × 320 × 160 mm, readout = 256-320, 1.0-1.25 mm acquired isotropic spatial resolution, VENC of 50-350 cm/s (case specific). Respiratory gating was performed with an adaptive gating scheme based on bellows readings, resulting in a scan time of approximately 10 minutes with 50% respiratory gating efficiency. To reliably achieve high quality images, several correction schemes were applied to account for effects of T1-saturation, trajectory errors, motion, and aliasing associated with undersampling. The PCVIPR data

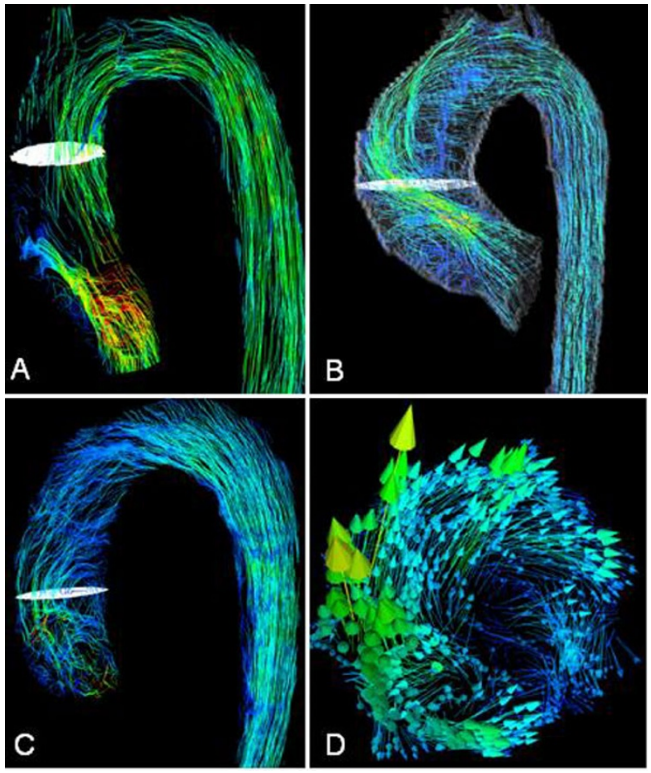

Figure 1
Laminar (A), vortical (B), and helical (C, D) flow patterns were observed in the ascending aorta. Velocity vectors (D) demonstrate a large tangenital velocity component in helical flow.

	PATIENT (n=11)	VOLUNTEER (n=10)
peak |v| (cm/s)	94.9 +/- 70.3	119.9 +/- 33.1
mean |v| (cm/s)	29.6 +/- 21.84	52.7 +/- 12.3
tangential %	47.7 +/- 20.1	4.76 +/- 1.9
max diameter (mm)	45.1 +/- 5.3	29.3 +/- 2.1
flow pattern	4 vortical 7 helical	10 laminar

Figure 2
MRI flow quantification comparison between volunteers and aneurysm patients.

were reconstructed as magnitude images, velocity vector fields, and angiograms calculated similar to complex difference images and stored in a format specific to the engineering visualization software Ensight (CEI, Apex, NC). Processing steps were developed to allow for interactive cross-sectional analysis for velocities in volumetric cine datasets, a feature currently unavailable in medical imaging software. Velocity fields were analyzed in the ascending aorta to provide measurements of peak velocity, mean velocity, and the percentage of velocity orthogonal to the direction of flow. Streamline and particle tracing visualization approaches were explored to characterize helical, vortical, and laminar flow patterns.

Results

3D visualization was performed successfully in each case, revealing different flow patterns in patients and volunteers (Fig. 1). Healthy volunteers show mainly laminar flow patterns in the ascending aorta, while in patients there is greater helicity and vorticity observed. Velocimetric analysis confirms these qualitative assessments, as patients present with increased tangential velocities orthogonal to the direction of the blood vessels (Figure 2).

Conclusion

Assessment of the velocity components of aortic blood flow may have revealed a diagnostic biomarker of disease progression in AscAA. Further investigation is needed to determine whether increased tangential velocities lead to further dilation, dissection, or rupture.